Simulating responses of Northeastern China forests to potential climate change[1]

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Abstract A simulation study on the responses of forests in Northeastern China to possible climate change was done by running NEWCOP, a computer model of forest stands "gap" dynamics with a set of parameters of 24 tree species. Based on the simulation, climate change will continue to make coniferous trees less and less and deciduous trees more and more. By the end of 100a transient process and 100a equilibrium climate period, forest biomass is reduced by a total of 6,531 million t dry material for the whole region of NE China. There is only a small area in the north on which there stands more biomass than without climate change. Korean pine will be first tree species which decrease by the most amount. In the northern part of NE China, oak forest will cover much more area with climate change and the larch forest may cover less area than it does at present. In the middle part areas, coniferous and broad-leaved mixed forest will remain, but the portion of deciduous species in composition of forest will increase. In the southern part areas, Korean pine will become companion tree species and its distribution area will greatly decrease.

Key words: Climate change, Gap model, Forests, Northeastern China.

Introduction

It is sure that present elevations of CO_2 and other greenhouse gases induced by human activities are making global climate go through inexperienced changes (Schlesubger 1987). The current quasi-equilibrium states of biosphere ecosystem, especially terrestrial ecosystems, would be broken because the structure, function, distribution and the dynamics of any existed ecosystems are the results of long term adaptation of bio-system to current climate. The ecosystems distributed in high latitude area would have much bigger change (Bonan 1990; Smith 1993; Shugart 1990). This is the main reason that we focus on effects of possible climate change on forests in Northeastern China where is just in or close to the high latitudinal area. There are two more reasons to make this study be of special importance. First, the northeastern region has been being the largest timber source in China since the beginning of this century so that any correct prediction may be good to Chinese economy. Second, very large amount of natural forests and less-disturbed forests are still kept good across the whole region. This is very useful to testing and calibration of ecology theory and models under the conditions without climate change.

In this paper, we apply NEWCOP (NorthEastern Woods Competition Occupation Processor) (Yan Xiaodong et al. 1995, 1996; Zhao Shidong et al. 1995) to make a primary estimation on the sensitivity of forests in Northeast China to climate change. At present, the research on transient response of terrestrial ecosystem to perturbed climate has been widely thought of as one of important topics on global change (Smith 1993). Therefore, this study focus on the transient response of northeastern China forest to transient climate change for correct management of forests of this region.

Sites and method

The forests of the northeastern China

This research area was about 1.28 million km^2, which ranges across about 120°~135° E and 39°~55° N. It was divided into three zones of forests based on climate zone and dominant tree species (Wu Zhenyi 1980).

Warm temperate deciduous broad-leaved forest occurs in the southwest corner of research region, in which original vegetation has been disappeared because of human activities. Dominant tree species are *Quercus* spp. and some pines (*Pinus* spp.).

Temperate broad-leaved and conifer mixed forest can be seen in the areas of latitude 41°~50°N, where Korean pine (*Pinus koraiensis*) is dominant tree species mixed by many broad-leaved tree species such as *Tilia* spp., *Quercus* spp.), *Ulmus* spp., *Betula* spp., *Populus* spp., *Fraxinus* spp, *Acer* spp., and so on. At some sites, some coniferous trees, firs (*Abies* spp.) and spruces (*Picea* spp.) for examples are also companion tree species. In general, Korean

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pine takes up 30%~50% or more in composition, The biomass of forest community is about 250~300 t/hm^2 (Li Wenhua 1981; Xu Zhenbang 1985).

Cool temperate coniferous forest occurs on the far north part of the research region, in which frequent spring drought and cool climate make larch (*Larix gemilini*) be dominant tree species mixed by birches, aspens and Mongolia pine (*Pinus sylvestris* var. *mongolica*). Fire ecology maintains the long-term stability of this type forest. At most case about 90% composition of forest community is larch, and forest biomass is 115-285 t/hm^2 (Fen Lin 1989).

Considering the feature and distribution of natural forests of Northeast China, our research focus on the 3 types of forests mentioned above except for deciduous broad-leaved forest because of its less natural distribution and intensive human disturbance.

Method

Model

The great progress on research of dynamics of forest growth and regeneration since 1970's has been set, and individual-based "gap" model is widely used. The model can present the growth, mortality and regeneration processes through simulating several gap-sized (about 1/12 hm^2) plots and applying Monte calo technique (Shugart 1977, 1984). This type of model was applied to simulate deciduous forests in the east of USA in the original study (Botkin *et al.* 1972), but it was also proved to be able to describe spatial structure, species composition and production dynamics of the various forest types over whole world (Shugart 1990, 1984). Because this type model generally adopts climate variables (monthly mean temperature, monthly mean precipitation, drought index, degree days and so on) as driving variables of running model, it can be conveniently used in study of vegetation-climate relations. Now, the model of this family is suggested to be widely applied to assess the response of forests to potential climate change.

A gap model KOPIDE (Shao Guofan 1989) to simulate the forests in Northeast China included too few tree species and was only suitable for broad-leaved Korean-pine mixed forest. Now a new model NEWCOP (Yan Xiaodong *et al.* 1995, 1996) has been developed, which has been proved to be able to simulate various forests in Northeast China through testing NEWCOP model on forests along vertical landscape zones in Changbai Mountain.

NEWCOP is rewritten from FORET (Shugart 1977; Post *et al.* 1996) with considering life history and refining regeneration and growth simulation. The model can reproduce the mortality, regeneration and growth dynamics of 28 tree species, almost all important tree species in study region, by simulating trees' dynamics of 20~50 forest stands sized 800 m^2. The model shows very strong ability to reproduce the current existing forests and running is driven by climate variables: monthly mean air temperature and precipitation. It is suitable for testing the sensitivity of forests to potential climate change.

The parameter requirements of species of NEWCOP model include tree demography, life history and physiological parameter (Table 1). The requirements of environmental parameter include site background and climate parameter as Table 2.

Table 1. Species parameters requirement for NEWCOP

Parameters	Description
A_{max}	Maximum age of species
D_{max}	Maximum DBH recorded
H_{max}	Maximum height
G_{max}	Growth parameter uncorrected by environmental stress
$DEGD_{max}$	Maximum >5°C effective degree-days in the species range
$DEGD_{min}$	Minimum >5°C effective degree-days in the species range
Rc	Renew ability under without disturbance
Rf	Renew ability after fire
Ro	Renew ability under other disturbance(wind, cutting)
Lt	Shade tolerant ability
Dt	Drought tolerant ability
Ft	Flood tolerant ability
Nt	Poor tolerant ability
P	Percentage of term of shading evergreen species

Table 2. Environmental parameter requirement for NEWCOP

Parameter	Description
LAT	Latitude of site, [°]
FC	Soil field capacity , cm
WP	Soil wilt point, cm
N	Soil fertility, kg/(hm^2•a)
Ta	Mean monthly air temperature
Td	Ta's long-term standard deviation
Ra	Mean monthly air precipitation
Rd	Ra's long-term standard deviation

Analytic methods

In this study, response of forests to climate is estimated by separately considering distribution of forest types and dynamics of typical forests. For estimating the distribution of forests, the northeastern region of China is divided into 605 grids (0.5°×0.5°). On each grid, NEWCOP simulator is run by 50 plots. For investigation of dynamics of typical forests, 3 typical sites are selected to run the model NEWCOP each of which 20~40 plots observed forest stands are called to join the simulations. (1) Wuying (at elevation 400 m) represents the sites of broad-leaved Korean pine mixed forest; (2) Alihe (at elevation 600 m) represents the sites of cool temperate conifer forest (larch forest); (3) Baihe (at elevation 740 m) represents the sites for deciduous mixed conifers forest. The current condition of sites is listed in Table 3.

The current climate data on 0.5° ×0.5° grids are from Leemans et al. (1990). And current climate data of each typical site is derived from report of local climate station. In order to test the sensitivity of forests to climate change, GFDL, the global circulation model, which was developed by Geophysical Fluid Dynamics Laboratory, and GISS model, are used to construct the $2XCO_2$-climate change scenario.

Table 3. Current natural condition of studied sites

Site	Latitude	Longitude	Elevation /m	Soil fieldcapacity /cm	Soil wilt point /cm	Soil fertility /kg•hm^{-2}•a^{-1}	Forest type	Disturbances
	50°~54°N	120°~135°E		15	7	8000	conifer	fire
605 Grids	44~50°N	120°~135°E		28	15	12000	mixed	wind
	40°~44° N	120°~135°E		24	12	10000	mixed	wind
Wuying	47°43'N	128°27' E	400	28	15	12000	mixed	wind
Baihe	42°01' N	128°05' E	740	24	12	8000	Mixed	wind
Alihe	50°35' N	123°44' E	600	15	7	6000	Larch	fire

It is easy to know the current vegetation type stood on each grid and each site, but we can hardly get tree data. Therefore, we used the methodology used by Pastor & Post (1986) to simulate the transient response of forests to a step by step change of climate. The current forest composition and structure are set to be the forest formed through 300a natural growth and succession after clear-cutting or other disturbance. This can be produced by running NEWCOP model 300a from bare floor on the local climate and soil condition. Then, more than 200a simulation was made to get the forest dynamics on each grid or each typical site with no climate change in the future 200a. Running NEWCOP from current forest (formed through 300a simulation) simulates the dynamics of forest on each grid or each typical site with climate change under the year-by-year climate condition formed by the following method: It is set to reach GFDL $2XCO_2$ climate in 100a. We assume that the climate precipitation and air temperature will change linearly in the 100a. In the next 100a, we let GFDL $2XCO_2$ climate be a equilibrium state. Therefore the new climate condition (GFDL $2XCO_2$ climate) will be kept no change 100a.

Through the comparison of two results of simulation under the conditions without climate change and with climate change, we can estimate the response of forest to climate change. Of course, this is a ideal estimation because of strong assumption about climate change data and current forest database.

Results

Response of forests dynamics to climate change

Responses to climate change at each site are strongly dependent on the current vegetation. The deciduous mixed by Korean pine forest at Baihe (elevation: 740 m, Fig. 1 and Fig. 2) may change very much under transient GFDL $2XCO_2$ climate change scenario. If current climate were to keep unchanged, Korean pine would increase its composition from, 30% (at present time) to 60% within 200a to dominate the forest stand. In the meanwhile, composition of deciduous species would be reduced, such as ash from 30% to 15%, oak from 15% to 5%, and only that of lime keeping constant. The stored biomass would be increased from 250 to 270 t/hm^2. Compared with the situation of no climate change, under transient GFDL $2XCO_2$ climate change scenario, Korean pine may disappear in forest stands within only 100a, so will lime. At same time interval, the biomass stored by stands should decrease greatly (from 250 t/hm^2 to 100 t/hm^2). The biomassof forest stands could not restore to 150 t/hm^2 untill 200a when deciduous trees, such as ash, oak and other hardwoods, dominate the forest stands. It should be paid more attention to that the quick death of biomass of forest occurs at near to 100a from now on when the biomass dieback by 70% within only 20a.

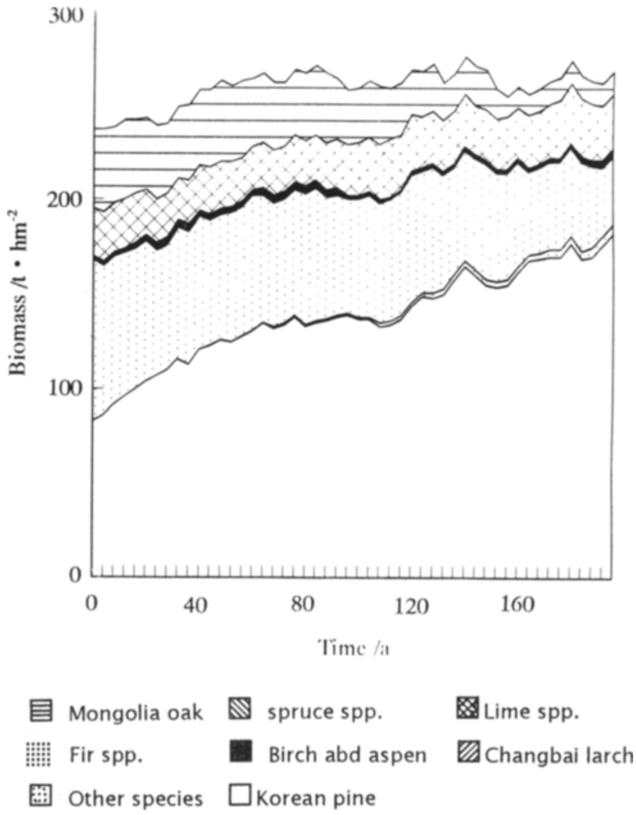

Fig. 1. Species composition by forest biomass from standing forest(North slope site of Changbai Mt., Elevetion 740 m) without climate change.

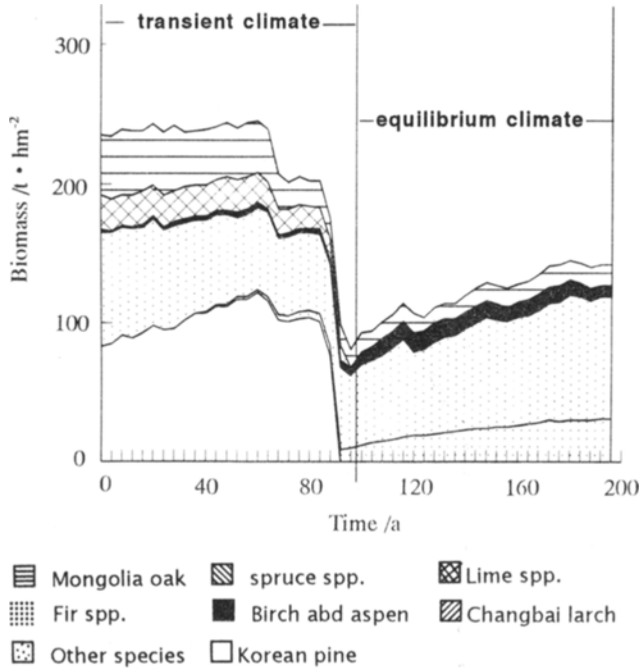

Fig.2. Species composition(by biomass) of standing forest (Changbai Mt. North slope site, Elevation 740 m) with the GFDL 2XCO$_2$ climate change scenario from the year 1979.
The years 1979-2079 for linear transient climate, 2079-3079 for equilibrium climate

Another response can be shown as that of Alihe site (Fig. 3-4). The transient GFDL 2XCO$_2$ climate change scenario may make the climate condition to be drier and warmer than current condition. This makes the dominant species-larch to be unsuitable to the condition. Oak can quickly replace the larch as dominant species because it can tolerate drier condition compared to larch and its optimal growth DEGD is higher. It should be noticed that oak is available now in current forest there. Therefore, for this site seed disperse is not a problem.

At the Wuying site, Yichun (Yan Xiaodong *et al.* 1996), with transient GFDL 2XCO$_2$ climate change scenario, Korean pine may disappear faster as it is climax forest ecosystem. Korean pine and lime would disappear within less 80a when the forest biomass could be less than 50 t /hm^2. But unlike Changbai Mt. Forest, the restoration of this site is fast. It takes only 100a to adjust forest biomass up to 200 t/hm^2. This lead the oak dominate forest and form an oak forest. There may be two reasons for explaining the result: Wuying may change to dry faster, and the original trees were too old.

We can compare the effect of different climate change scenarios on the forest stands on Wuying site. Compared with transient GFDL 2XCO$_2$ climate change scenario, the

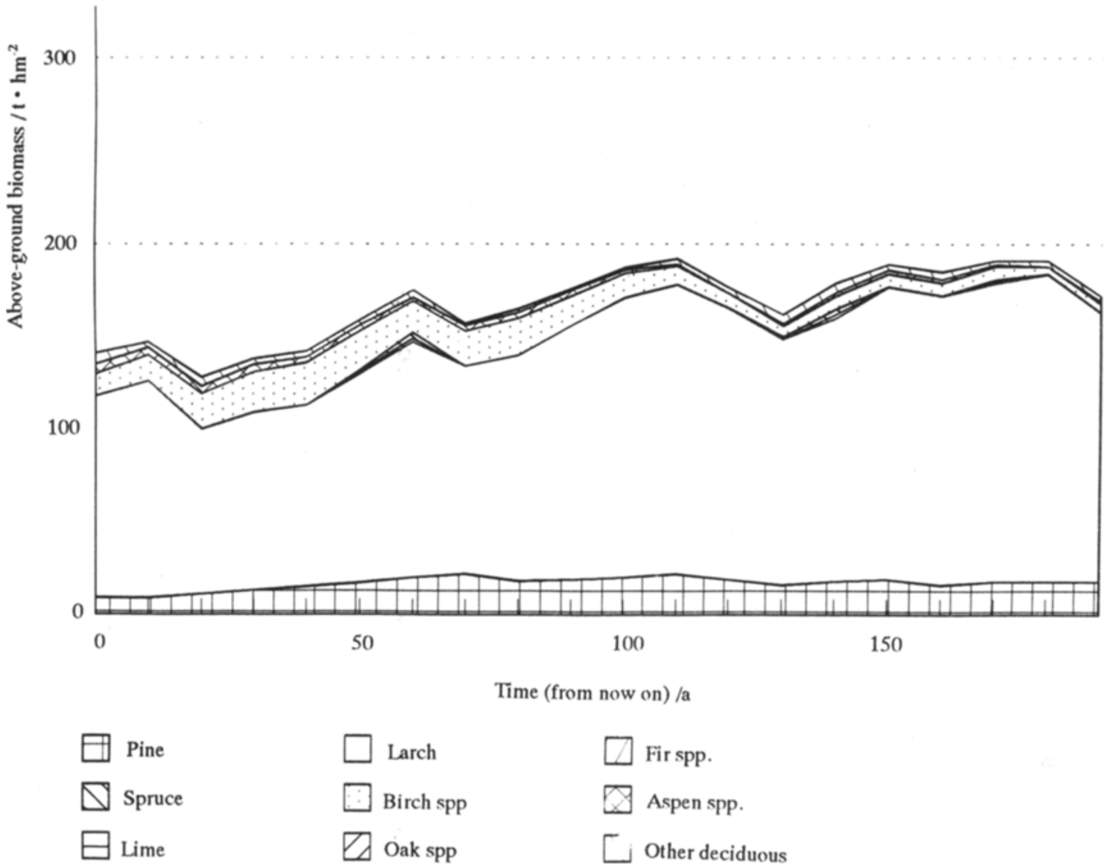

Fig. 3. Forest dynamic of Daxing'an region (Alihe site 50°35'N, 123°44'E) without climate change.
Xing'an larch is dominant species.

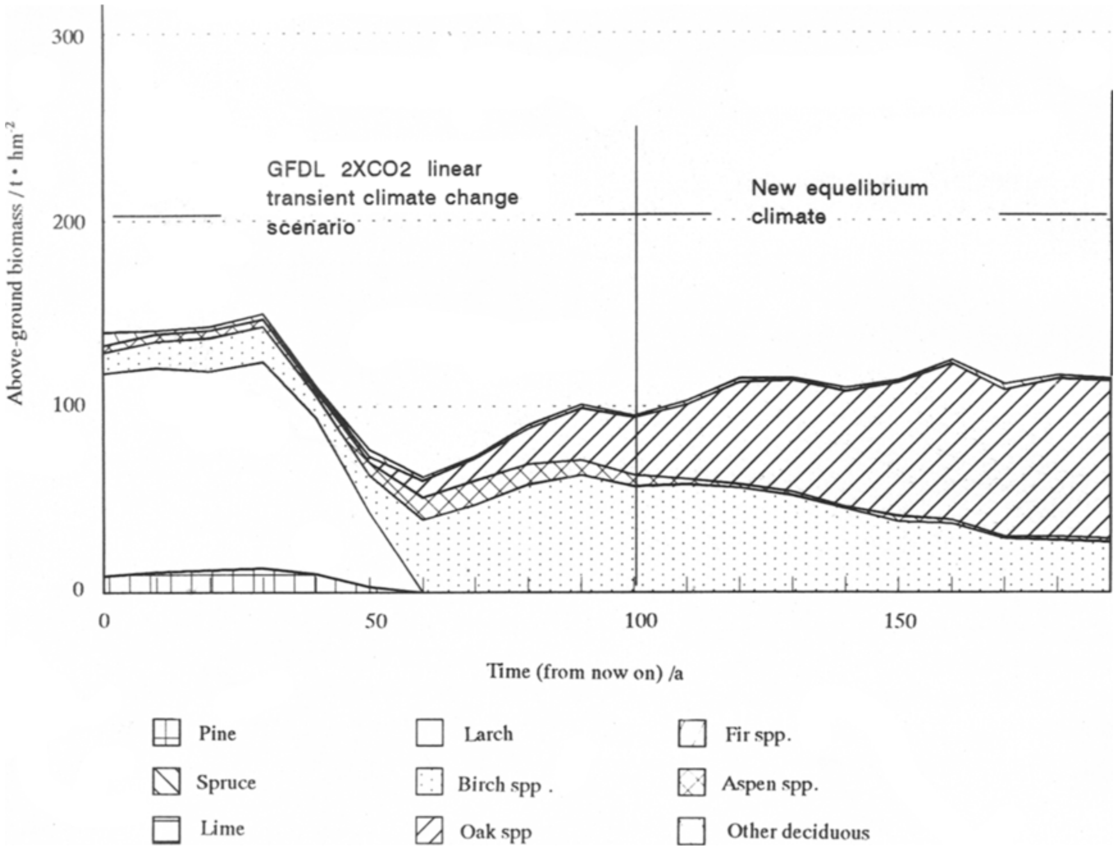

Fig. 4. Forest Dynamics of Daxing'an Mt. (Alihe site, 50°35', 123°44') with climate change

Mongolia Oak replace the dominant position of Xing'an larch

transient GISS $2XCO_2$ climate change scenario could not make Korean pine and lime disappear, but lowering importance in forest. After 400a from now on, Korean pine could take up only 25% in composition of forest biomass, and ash will increase from almost zero to 30%, oak from zero to 10%. So different transient $2XCO_2$ climate change scenario may have different effects on forest stands, but the effects could have a similar trend: increasing deciduous tree species and decreasing evergreen conifer tree species (like Korean pine).

Simulations indicates that the difference of current climate conditions and forest types can lead to different response of forest dynamics to climate change. So the large number of simulations across the region are very necessary.

Effect of climate change on distribution of forests

300 years simulation was made on the background of current climate pattern from clear-cutting floors (Fig. 5). The maps of simulated forest distribution can predict where there exists forest and any concerned tree species. It is just as a real map does, only with a little exception that it may involve some issues such as species diffusion block, climatic amplitude or accidence and other complicated things. Forests biomass is well predicted in the present simulation. Except on some parts of small area, both the biomass of forests and biomass of dominant species are correctly predicted on the most parts of the region. Species compositions of forests strongly depend on the age of simulated plots from the beginning. In order to reach real composition of forest, 300a simulation is needed in the northern part area and 400a simulation is needed in the south. There are some errors in the simulation, particularly in the north. Since lack of the disturbance or climatic oscillation in the simulation, the composition of larch (*Larix gmelinii*) forest is predicted not to remain and it would be replaced by spruce (*Picea koraiensis* & *Picea jezoensis*) (probably because of without drought accidence at present simulation). It is also because no climate oscillation (resulted from available climate database) that oak forest and Korean pine forest occur at many sites which are covered by grassland or desert in fact. In sum, the present simulation can fairly show the forest distribution, productivity and even quite accordant to tree species distribution, and can partly express the composition of forest. If some little process such as climate variability and natural disturbance are added to simulation, most of errors will be eliminated. So the simulator NEWCOP can be used to study the sensitivity of forest to climate change.

According to the simulation, only 100a transient climate

change can lead to great changes in species composition and productivity of forests. In most sites, the stored forests biomass is 100~255 t/hm^2, less than that in the sites without climate change. It is mainly because of dieback of forest trees resulting from unsuitability to new climate pattern (Fig. 6). And in this region, total difference of forests' biomass between sites with climate change and without climate change is predicted to be 12046 million t dry material. In Changbai Mt. region, the dominant position of present Korean Pine will be replaced by deciduous tree species; In the north, such as Xiaoxing'an Mt. region, Korean Pine is still in the dominant position, but the portion in the forest composition will be reduced. Only oak can be expected to increase in most sites, and become dominant species in the Daxing'an Mt region because of the drought climate, and other species to be expected to increase are some broad-leaved species such as birch (*Betula platyphylla* & B. *dahurica* etc.) and *Tilia amuerensis* etc.. In most sites, spruce is predicted to greatly decrease. The area not to be adaptive to trees living is predicted to increase. Very interesting, those are just the places where forests are predicted to occur but in fact no forest exists currently.

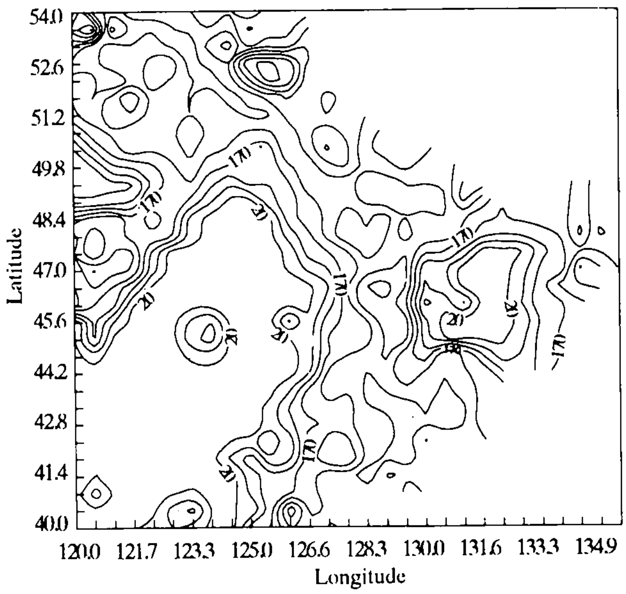

Fig. 6. Northeastern China forests distribution by stand biomass (t/hm^2) after 100 years GFDL 2XCO$_2$ climate change

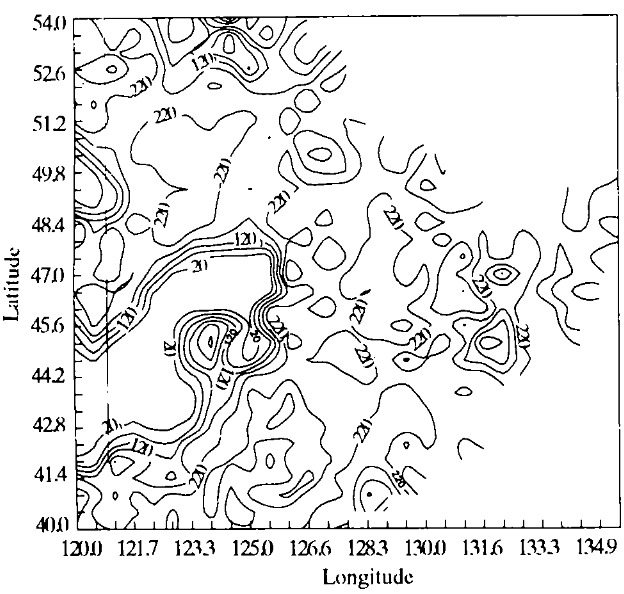

Fig. 5. Northeast China forest distribution of present time

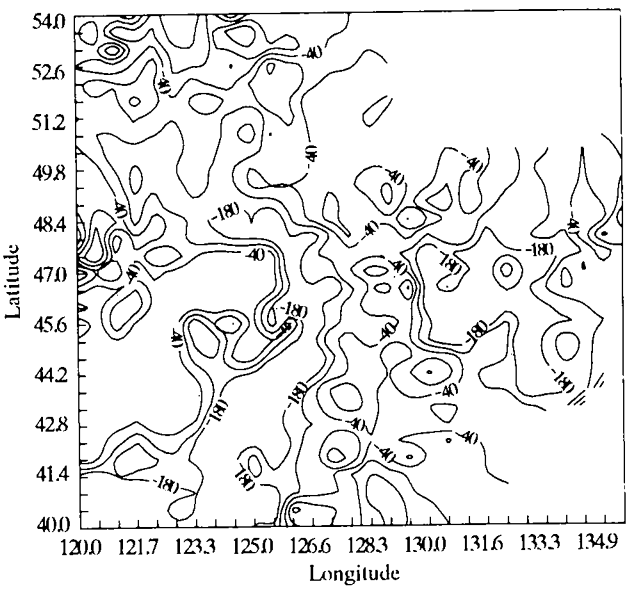

Fig. 7. Biomass(t/hm^2) loss of Northeastern China forest resulted from 100 years GFDL 2XCO$_2$ transient climate change

Based on the simulation, climate change will continue to make coniferous trees less and less and to make deciduous trees more and more. By the end of 100a transient process and 100 years equilibrium climate period, forest biomass is reduced by a total of 6,531 million t dry material. through integrating computation.(according to Fig. 7) There is only a small area in the north on which there stands more biomass than that without climate change. Korean pine will be first tree species that may decrease in large amounts. The following thing is important:

In the north, oak forest will cover much more areas, compared to that without climate change, and larch will be in dominant position in little part area. In the middle part, coniferous and broad-leaved mixed forest will remain but the portion of deciduous species in composition of forest will increase. In the south, Korean Pine will become companion tree species and its distribution area will greatly decrease.

Discussion

Our research shows that under without human disturbance the forests in the northeastern China may help increase the air CO_2 with the global warmer within 100~200a because of trees' dieback of the forests during the period. If people can introduce the some warm-like or dry-like tree species, the positive feedback may be weaken.

Our simulation does not consider the fertilization of CO_2 and other effect. In fact, if you thought the forest will never be like what we show, you should be possible to find the reason from those factors we did consider.

Our model is a patch-sized model, which generally can not deal with landscape and regional issues. But if we can consider each local study site to be homogeneous in environmental condition and current forest type, the results should be reasonable.

Although this study is just a primary step, the conclusion that the deciduous tree may dominate the northeastern China forests is just the same as that of palaeo-climatological study conducted by another group researchers.

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